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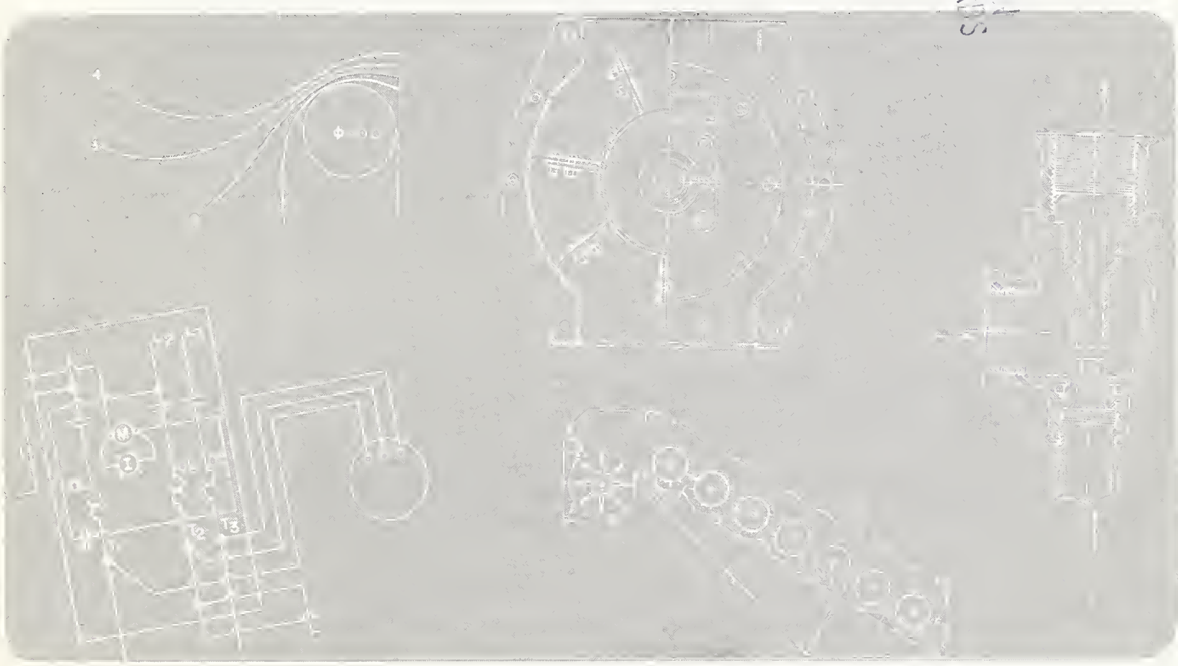
Energy Requirements of Cotton-Bale Packaging Systems



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Energy Requirements of Cotton-Bale Packaging Systems

By W. Stanley Anthony,[1] Joseph L. Ghetti,[2] and Durwood E. Hayes[3]

ABSTRACT

The electrical energy required to package cotton bales in three modified-flat and eight gin-universal-density packaging systems was surveyed in an effort to develop the data needed to achieve significant reductions in the energy required to package cotton. The major energy consumers in these systems are the press and the tramper (mechanical or hydraulic). The presses of the gin-universal-density systems used over eight times more electrical energy than that used by the presses of the modified-flat systems. The hydraulic trampers required nearly six times more energy than that used by the mechanical trampers. Regression equations were developed to describe the variation in electrical energy as a function of ram cross-sectional area, press horsepower, and compression density; to explain 74% of the electrical energy consumption in terms of only one variable—net restraint density; and to predict the net restraint density of a bale of cotton in simple terms. Index terms: cotton, cotton-bale characteristics, cotton-bale packaging systems, cotton ginning, energy, packaging.

INTRODUCTION

Changes in bale-packaging systems and marketing techniques since 1970 have produced substantial changes in the energy required to package cotton and in the physical dimensions of cotton bales. Three bale-packaging systems are prevalent today—modified-flat, gin-universal-density, and compress-universal-density. Modified-flat bales are packaged at gins at densities of 12 to 15 lb/ft^3 and are later repackaged at compresses to become compress-universal-density bales with a minimum density of 28 lb/ft^3. Gin-universal-density bales are packaged at gins to a minimum density of 28 lb/ft^3. Freight rates are much lower for bales that have a density of at least 28 lb/ft^3.

Modern bale-packaging systems in cotton gins consist essentially of a tramper, which compacts the cotton to low density; a press, which compresses the cotton to much higher densities; and an automatic strapping subsystem. The tramper and the press are the two major energy consumers in a bale-packaging system, while the automatic strapping subsystem uses a relatively insignificant amount of energy. Current trampers are powered hydraulically or mechanically. Most gin presses employ hydraulic rams to compress cotton. The press for modified-flat packaging systems typically

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requires less than 50 horsepower, whereas the press for gin-universal-density packaging systems may require as much as 250 horsepower.

Anthony and McCaskill (1973, 1976, and 1977) concluded that the force required to compress rectangular bales of lint cotton is primarily a function of the compression density (density to which the bale is compressed) and moisture content of the cotton. The power required to compress the bale is also a function of the rate of compression, as well as the horsepower, ram size, and other operating characteristics of the press subsystem.

Previous studies have shown dramatic differences in the energy requirements of the different bale-packaging systems (Anthony et al. 1975, Shaw and Ghetti 1977). The purpose of this study was to investigate the engineering parameters that govern the energy required to package cotton in an effort to develop the data needed to achieve significant reduction in that energy.

EQUIPMENT, PROCEDURES, AND ANALYSIS

The energy required to package cotton bales produced in representative modified-flat and gin-universal-density packaging systems in the Mississippi-Arkansas-Lousiana area was surveyed for six ginning seasons, from 1973 to 1978. Surveys were conducted for three modified-flat and eight gin-universal-density systems. The physical characteristics of the bales were also measured.

Kilowatthour meters were installed on each press motor or motors and each tramper motor. The meters were read before the ginning season, twice during the season, and at the end of the season. The total kilowatthours used by each tramper and press were divided by the number of bales packaged during the same time frame to establish the per-bale energy requirements.

The physical dimensions and time requirements of each of 25 consecutive bales were measured for each gin during each ginning season. These values were then averaged to represent the gin for that time frame. The following dimension and time variables were measured:

Ginning time per bale (seconds).
Bale tie-out time (seconds).
Ram travel time (seconds).
Net bale weight (pounds).
Platen separation (inches).
Bale width (inches).
Bale length (inches).
Bale thickness at the tie (inches).
Bale circumference at the tie (inches).
Bale thickness at the hump (inches).

The bale dimensions, with the exception of circumference, were measured with locally fab-

Table 1.—Electrical energy consumption of trampers

Ginning season	Kilowatthours per bale consumed at gin No. —										
	[1]1	[1]2	[2]3	[2]4	[1]5	[1]6	[2]7	[2]8	9	[1]10	[1]11
1973	0.23	([3])	0.73	([3])	0.18	([3])	1.11	1.22	[1]0.18	0.20	([3])
1974	.25	.17	.95	1.58	.23	0.24	1.55	1.30	[1].27	.25	0.22
1975	.26	.18	.88	1.72	.20	.32	1.60	1.20	[1].21	.31	.20
1976	.27	.26	1.47	1.55	.21	.27	1.51	1.20	[1].23	.31	.21
1977	.22	.15	1.03	1.44	.15	.24	1.04	1.28	[2]1.05	.28	.20
1978	.24	.24	1.12	1.64	.19	.22	1.77	1.25	[2]1.32	.28	.21
Mean	.25	.20	1.03	1.59	.19	.26	1.43	1.24	.54	.27	.21
Standard deviation of means	.01	.02	.10	.05	.01	.02	.12	.02	.21	.02	.00
Coefficient of variability, %	7.6	23.7	24.6	6.58	14.1	15.1	20.3	3.4	93.0	15.3	4.0

[1]Mechanical tramper.
[2]Hydraulic tramper.
[3]Data not available.

ricated calipers. Time was measured with stop watches, and bale circumference was measured with a steel measuring tape. Net restraint density, gross restraint density, and compression density were calculated from the measured variables. Net restraint density is defined as the density after the bale is removed from the press and does not include the weight of the bale-covering and restraining materials. The width and thickness measurements were made at the tie. Gross restraint density includes the weight of the bale-covering and restraint materials. Compression density is based on measurements taken before the bale is removed from the press.

Analyses of variance (factorial, completely random design) were used to separate the effects of the type of press used (modified-flat or gin-universal-density) and the year (1973-78) and their interaction on tramper energy and press energy. Stepwise regression analyses were used to develop prediction equations for press energy consumption and restraint density.

RESULTS AND DISCUSSION

Tramper Energy

The electrical energy required by the trampers to initially compact lint cotton is summarized in table 1. The mean of the electrical energy consumption varied from a low of 0.19 kWh/bale for a mechanical tramper (gin 5) to a high of 1.59 kWh/bale for a hydraulic tramper (gin 4). The mean energy consumption was 0.23 and 1.32 kWh/bale for the mechanical and hydraulic trampers, respectively. Variations in tramper energy consumption between years were probably attributable to bale weight, moisture content, and ginning rate. The large differences in tramper energy consumption for gin 9 for the years 1973-76 and 1977-78 were the result of replacing the mechanical tramper with a hydraulic tramper.

No significant differences existed in the electrical energy required by the trampers as a result of the type of press used (table 2). The lack of significance was due to the presence of mechanical and hydraulic trampers on both types of presses. The energy consumed by trampers is important, but the maintenance, life cycle, capabilities, and operating characteristics are equally as important.

Press Energy

The mean energy consump ion ranged from 0.17 kWh/bale (gin 1) to 0.38 kWh/bale (gin 3) and from 0.83 kWh/bale (gin 11) to 3.54 kWh/bale (gin 4), respectively, for the individual presses used in the modified-flat and gin-universal-density packaging systems (table 3). The mean of the electrical energy consumption for the eight presses of the universal-density systems was 2.17 kWh/bale, and the mean coefficient of variability was 17.2%. The mean for the three presses of the modified-flat systems was 0.27 kWh/bale. Thus, the presses of the gin-universal-density systems required over eight times more energy than that used by the presses of the modified-flat systems. However, the modified-flat bale must be recompressed later in order to achieve lower freight rates.

The packaging system at gin 9 was replaced before the 1977 season with a packaging system having different capabilities and energy requirements, resulting in a high coefficient of variability (47.5%). The coefficients of variability for the

Table 2.—Analysis of variance for electrical energy consumption of trampers and presses

Source of variation	Degrees of freedom	Mean square for electrical energy			*F*-value for electrical energy		
		Tramper	Press	Total	Tramper	Press	Total
Year	5	0.05	0.21	0.49	[1]0.15	[1]0.21	[1]0.22
Type of press	1	.69	48.38	59.74	[1]1.91	[2]49.54	[2]26.27
Year and type of press	5	.03	.07	.14	[1].08	[1].07	[1].06
Error	54	.36	.98	2.27	......	....	....

[1]Not significant at the 10% level of probability.
[2]Significant at the 1% level of probability.

other presses ranged from 4.0% at gin 11 to 26.6% at gin 5.

Analysis of variance (table 2) for the electrical energy consumed by the press indicated that "year" and the interaction between "year" and "type of press" were not significant at the 10% level of probability, whereas "type of press" was significant at the 1% level of probability. The lack of significance of the variable "year" and the high coefficients of variability for some of the presses appear contradictory. However, variability was not consistently different for the same years for each of the presses and appeared to be somewhat random. From a practical standpoint, this variation can be attributed to changes in the operating procedures for the presses as well as to differences in the compressive characteristics of the lint cotton.

Table 4 summarizes the energy requirements and some of the test variables for the modified-flat and gin-universal-density packaging systems during the 1973-78 ginning seasons for comparison. After 1973, the press energy for both systems increased substantially; however, no pattern was evident after 1974.

Stepwise multiple linear regression analysis yielded the following equation to represent the electrical energy required by a press to package cotton:

$$\ln_e E = -3.007 + 0.00185 P_{hp} + 0.00185 R_a + 0.0703 D_p, \qquad (1)$$

where $\ln_e$ = natural logarithm (base e),

E = electrical energy (kilowatthours per bale),

P_{hp} = press horsepower,

R_a = ram cross-sectional area (square inches),

and D_p = compression density (pounds per cubic foot).

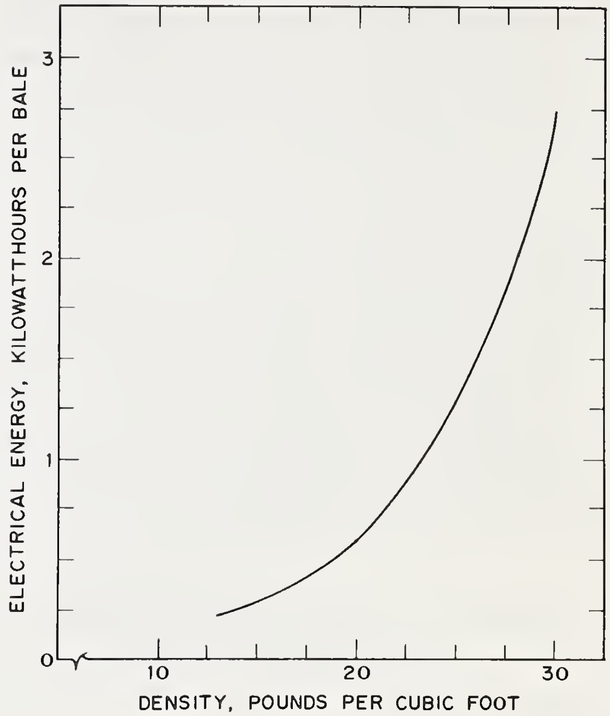

FIGURE 1. — Relationship of electrical energy and net restraint density for the bale-packaging systems.

Table 3. — Electrical energy consumption of presses

Ginning season	Kilowatthours per bale consumed at gin No.[1] —										
	1	2	3	4	5	6	7	8	9	10	11
1973	0.13	([2])	0.35	([2])	1.50	([2])	2.42	3.06	0.94	1.50	([2])
1974	.17	0.23	.41	3.48	1.63	1.13	3.60	3.32	1.13	1.80	0.87
1975	.15	.26	.36	3.87	2.80	1.23	3.46	3.19	1.33	2.10	.79
1976	.18	.29	.45	3.99	1.77	1.31	3.70	3.01	1.04	1.79	.83
1977	.11	.29	.35	3.04	1.89	1.43	3.05	3.15	1.73	1.65	.80
1978	.28	.28	.35	3.32	2.62	.87	3.96	3.10	2.84	1.79	.85
Mean	.17	.27	.38	3.54	2.04	1.19	3.37	3.14	1.50	1.77	.83
Standard deviation of means	.02	.01	.02	.18	.22	.09	.23	.04	.29	.08	.01
Coefficient of variability, %	35.1	9.4	11.1	11.1	26.6	17.7	16.4	3.5	47.5	11.2	4.0

[1]Gins 1-3, presses for modified-flat packaging systems. Gins 4-11, presses for gin-universal-density packaging systems.
[2]Data not available.

Table 4. — Selected test variables and energy requirements for the modified-flat and gin-universal-density packaging systems

Measurement	Bale packaging system											
	Modified-flat[1]						Gin-universal-density[2]					
	1973	1974	1975	1976	1977	1978	1973	1974	1975	1976	1977	1978
Press horsepower	50.0	50.0	50.0	50.0	50.0	50.0	173.8	173.8	173.8	173.8	168.8	168.8
Ram area ... square inches	55.0	55.0	55.0	55.0	55.0	([5])	283.5	283.5	283.5	283.5	262.8	262.8
Ginning rate ... bales/h	16.1	15.3	15.3	16.8	18.1	([5])	15.7	16.2	16.8	15.7	17.8	([5])
Bale weight ... lb	488.2	482.8	493.5	495.7	506.1	([5])	489.8	496.1	502.7	496.9	495.2	([5])
Bale length ... inches	55.6	55.8	55.9	55.9	55.7	([5])	54.5	54.8	54.6	54.8	54.6	([5])
Bale width[3] ... inches	24.8	25.3	25.3	25.2	25.4	([5])	20.6	20.8	20.8	20.8	20.6	([5])
Bale thickness[3] ... inches	41.9	41.6	42.3	41.5	43.2	([5])	27.5	27.7	27.9	27.8	27.6	([5])
Bale circumference[3] ... inches	118.1	119.5	120.8	119.5	122.5	([5])	87.2	86.7	87.4	86.7	86.7	([5])
Net restraint density ... lb/ft[3]	14.6	14.2	14.3	14.7	14.3	([5])	27.4	27.3	27.5	27.2	27.6	([5])
Gross restraint density ... lb/ft[3]	15.0	14.9	14.9	15.3	14.7	([5])	27.9	27.9	28.0	27.6	28.0	([5])
Electrical energy:[4]												
Tramper ... kWh/bale	0.23	0.46	0.44	0.67	0.46	0.51	0.58	0.70	0.72	0.69	0.72	0.86
Press ... kWh/bale	.13	.26	.26	.31	.21	.27	1.88	2.10	2.35	2.18	2.19	2.42
Total energy ... kWh/bale	.36	.72	.70	.98	.67	.78	2.46	2.80	3.07	2.87	2.91	3.28

[1]Values, with the exception of electrical energy, are averages of 75 bales or more.
[2]Values, with the exception of electrical energy, are averages of 200 bales or more.
[3]At tie.
[4]Values are the average for the total bales processed each year.
[5]Data not available.

The coefficient of determination for equation 1 was 0.772, and the F-value was highly significant (1% level). Since the data represent the bale presses currently in use and equation 1 explains over 77% of the variation in the data, equation 1 should adequately predict the electrical energy required to compress lint cotton.

The electrical energy required to compress lint cotton may also be estimated from the net restraint density (D_R) with the equation:

$$\ln_e E = -3.5980 + 0.1535 D_R. \qquad (2)$$

The coefficient of determination for equation 2 was 0.746, and the F-value was highly significant (1% level). Thus, equation 2 explains over 74% of the variation in the data and would suffice to estimate electrical energy requirements. The relationship between electrical energy and net restraint density is shown in figure 1.

Bale Characteristics

Average bale characteristics from the modified-flat and gin-universal-density packaging systems are shown in table 4. Press horsepower for the modified-flat systems was 50 and for the gin-universal-density systems was 173.8 for 1973-76 but dropped to 168.8 in 1977-78. Bale weights for both packaging systems were quite similar. Bale thicknesses for the modified-flat bales ranged from 41.5 to 43.2 inches, whereas for the gin-universal-density bales they ranged from 27.5 to 27.9 inches.

Net restraint density averaged 15.0 and 27.4 lb/ft^3, respectively, for the modified-flat and gin-universal-density packaging systems. Net restraint density for modified-flat bales is illustrated in figure 2. When bale circumference and weight are known, net restraint density can be estimated from this graph. Bales produced by gin-universal-density packaging systems fall into two width categories—20 inches and 21 inches. Figures 3 and 4 graphically illustrate the relationship between net restraint density and bale weight for the different circumferences of the 20 and 21 inch bales, respectively. Figures 2, 3, and 4 simplify the calculation of net restraint density.

Stepwise regression analysis of 1,650 data points indicated that the net restraint density of a bale could be predicted from the physical dimensions of the bale by the equation

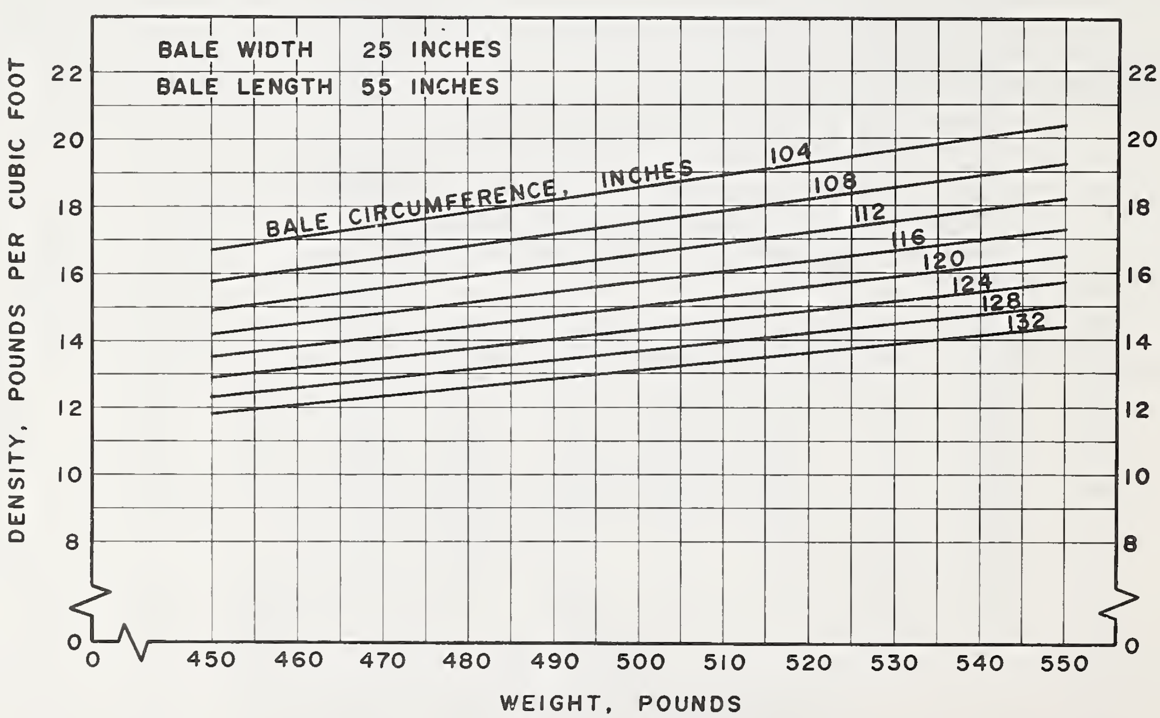

Figure 2. — Relationship of density, net weight, and bale circumference for modified-flat bales 25 inches wide and 55 inches long. Bales were measured within 30 minutes after being released from press.

$$\ln_e D_R = -0.2079 + 1.0349 \ln_e Q - 0.0409W - 0.0172L - 0.0129C, \quad (3)$$

where D_R=net restraint density (pounds per cubic foot),
Q=quantity of cotton (pounds),
W=width of bale (inches),
L=length of bale (inches),
and C=circumference of bale (inches).

The coefficient of determination for equation 3 was 0.997, and the F-value was highly significant (1% level). Since the data are representative of typical packaging systems in the United States, equation 3 should adequately predict net restraint density.

Net restraint density is independent of the materials used to cover and restrain bales, and prediction equations based on net density are more accurate than those based on gross density. However, gross restraint density, which includes the covering and restraint materials, is used to determine qualification for lower freight rates that typically apply to universal-density bales. The average gross restraint density varied from 27.6 to 28.0 lb/ft^3 during the 1973-77 ginning seasons. The actual weights of the various bale-covering and restraint materials should be used to accurately calculate the gross restraint density from the net density of gin-universal-density bales. However, the gross restraint density can be estimated by adding a factor of 0.3 lb/ft^3 to the net restraint density when wire or steel strapping is used in conjunction with woven polypropylene, polyethylene, or burlap spiral bags. A correction factor of 0.65 lb/ft^3 should be used if new jute or compact jute is used.

SUMMARY

The presses of the gin-universal-density packaging systems used over eight times more electrical energy than that used by the presses of the modified-flat systems. Differences between years were not significant. The wide variations in the amount of electrical energy required to package gin-universal-density bales suggest that opportunities exist for significant reductions in energy requirements.

Regression equations were developed to explain over 77% of the variation in the energy required by the press subsystems. The most important variables were press horsepower, ram area, and

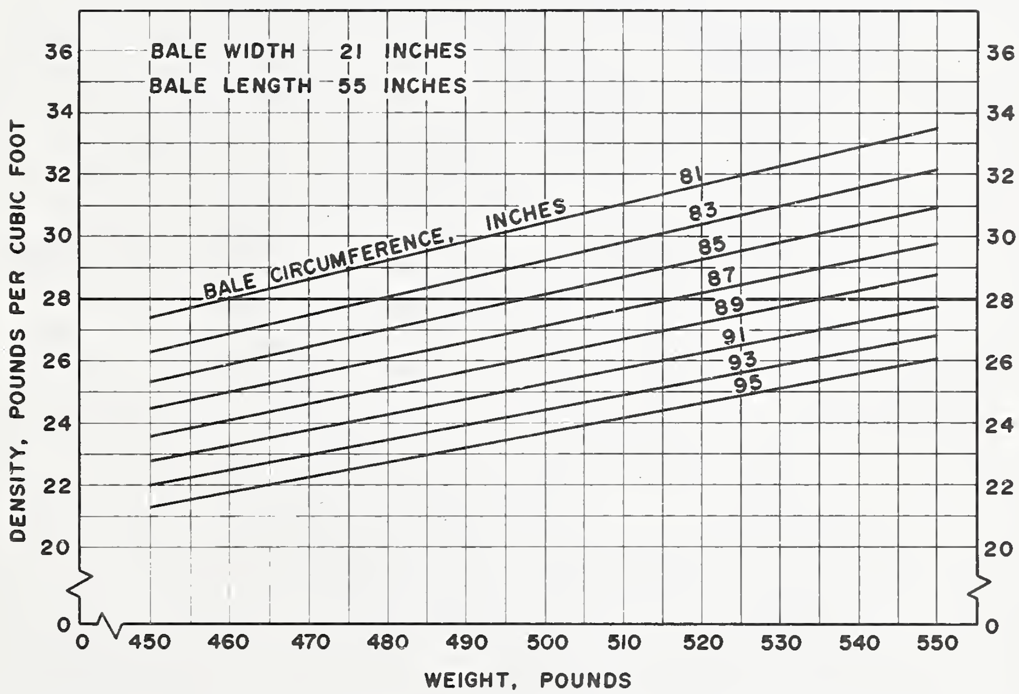

FIGURE 3. — Relationship of density, net weight, and bale circumference for gin-universal-density bales 21 inches wide and 55 inches long. Bales were measured within 30 minutes after being released from press. Bales with a density of less than 28 lb/ft^3 are not universal-density bales.

compression density. A regression equation for net restraint density was also developed to explain over 99% of the variation in the data. The primary variables were bale weight, length, width, and circumference. Thus, regression equations can be used to predict the characteristics of a bale packaging system.

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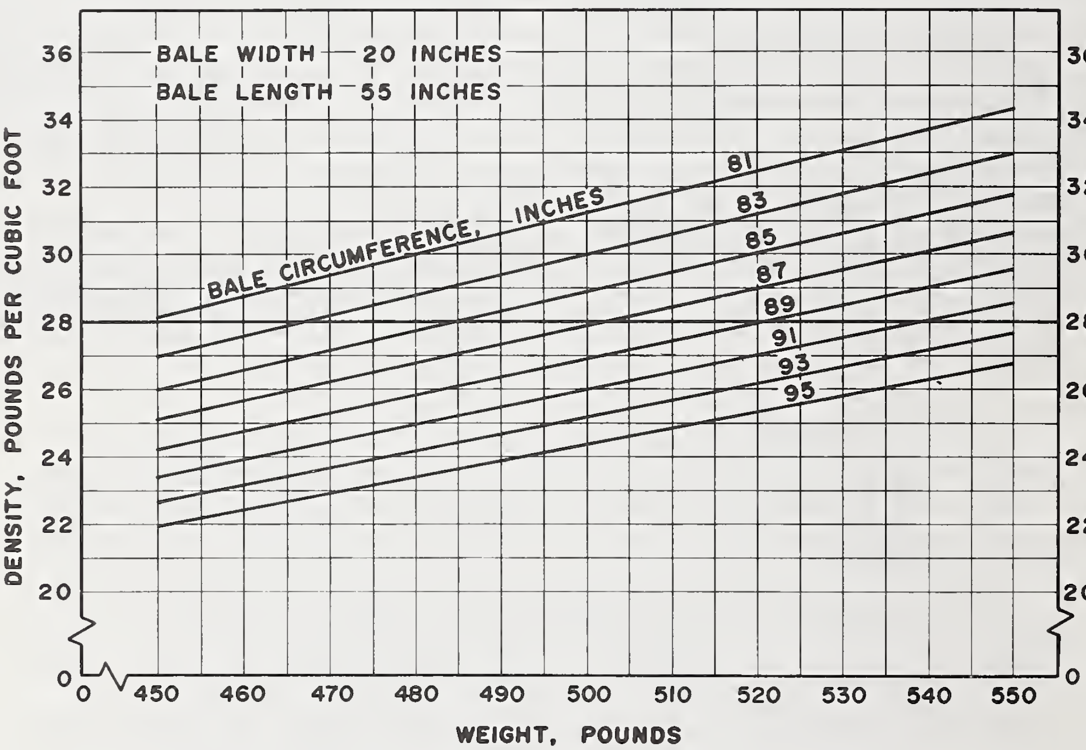

FIGURE 4. — Relationship of density, net weight, and bale circumference for gin-universal-density bales 20 inches wide and 55 inches long. Bales were measured within 30 minutes after being released from press. Bales with a density of less than 28 lb/ft^3 are not universal-density bales.

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